A SEARCH FOR X-RAY PULSATIONS FROM THE GALACTIC CENTER

by

France A. Córdova and Gordon P. Garmire
California Institute of Technology
Pasadena, California 91125

and

Walter H. G. Lewin
Massachusetts Institute of Technology
Cambridge, Massachusetts 02138

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"Search for Periodic Variations in the X-Ray Flux From the Galactic Center"

Principal Investigator: Gordon Garmire

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ABSTRACT

A search has been made for X-ray pulsations from the direction of the galactic center using data from the SAS-3 satellite. No periodic X-ray behavior was detected in the frequency interval 6×10^{-1} to 6×10^{-4} Hz and energy range 2.5 - 35 keV. For periods ≤ 60 sec, the upper limit to the amplitude of any pulsation in the 2.5 - 10 keV band is $\sim 1.7 \times 10^{-3}$ cts cm^{-2} s^{-1}. This corresponds to a pulsed fraction of $\sim 1.3\%$ of the total GCX flux. Somewhat higher limits apply for longer periods and for energies greater than 10 keV.

I. INTRODUCTION

X-ray emission was first detected from an extended (~ 2°) region in the direction of the galactic center by Kellogg et al. (1971). With the poor spatial resolution of the Uhuru detector used for this observation, it was not possible to determine whether the source was truly diffuse, or whether discrete sources contributed to at least part of the GCX flux. Discrete sources were later discovered in this region-- two transient sources (Eyles et al. 1975; Ariel-V Group, 1975), and at least three burst sources (Lewin et al. 1976). Since all of these sources were short-lived in nature, the question remained open as to whether discrete sources could account for the steady GCX flux.

A particularly interesting possibility was that the burst sources might have steady components whose total flux was observed as GCX (Lewin et al. 1976). A subsequent survey of this region during an NRL rocket flight is consistent with this proposal. Cruddace et al. (1977) were able to resolve GCX into a minimum of 4 discrete sources, and noted that each of the burst error circles overlapped at least one of the error boxes of these steady sources.

The next interesting question was the determination of the nature of the discrete GCX sources. Our objective was to look for periodic X-ray behavior from GCX. There was a considerable amount of SAS-3 data already in hand because of the large amount of time the satellite pointed in the direction of the center of the galaxy watching for bursts. While the rather large field of view (1.7° FWHM) of the SAS-3 Horizontal Tube detector would preclude association of any pulsations with one of the known discrete

GCX sources, it was still valuable to search for pulsations just to identify the kind of sources present at, or near, the Galaxy's center. If one or more pulsations were present, the large SAS-3 data base extending over three years would allow a more detailed study of these objects.

There is evidence that transient sources may arise frequently at the galactic center (Cruddace et al. 1977), and we know of two transients, A1118-61 and A05355+26 which exhibit long period pulsations of 405s and 104s, respectively (Ives et al. 1975; Rosenberg et al. 1975). Thus it was important for this study that each GCX observation be for a long enough duration to detect periods several minutes long, and that there would be several observations spaced widely apart, to accommodate the detection of a pulsating transient source.

With these objectives in mind, we made a preliminary search for pulsations from the galactic center using SAS-3 data from long pointings at GCX. In the following sections, we describe the data reduction procedures and summarize the results.

II. THE EXPERIMENT AND DATA REDUCTION

The data used for this analysis were taken with the Horizontal Tube system ($\sim 1.7^{o}$ FWHM) of the SAS-3 X-ray observatory (Lewin et al. 1976b). The argon-filled proportional counters in this system had a geometrical area of 115 cm^2 and covered the energy range 2.5 - 10 keV, while the xenon-filled counter had an area of 80 cm^2 and spanned the interval 8 - 35 keV.

The sampling length used in the analysis was 0.8314 s, thus restricting the search to periods greater than ~ 1.7 s. Although the data used here were from relatively long observations (a 6.3 h data block in 1976 Feb and a 18.9 h block on 1977 Feb), the analysis is probably insensitive to periods longer than 30 minutes because of severe source modulation due to spacecraft pointing jitter. Drifts often amounted to a cumulative drift of $\sim 1^{\circ}$ from the nominal pointing direction. (These drifts were corrected frequently.) The orbital period of ~ 94 minutes and its harmonics are clearly present in the power spectra (Figure 1).

A typical block of data is broken up with gaps due mainly to earth occultations and passage through regions of high charged particle fluxes. Segments of noninterrupted data might be anywhere from several minutes to ~ 30 minutes long. The average count rate per bin of 0.8314 s was calculated for each uninterrupted data segment and a weighted mean was derived for the entire data block from these individual averages. Then this weighted mean was subtracted from each data bin. Individual bad data points were rejected by requiring that each datum be less than 5σ greater than the average value of the previous 3 data values. Values of the bins during the gap intervals were set to zero; thus the entire data block had a zero average count rate. The data were then analyzed using the Cooley-Tukey fast Fourier transform algorithm. The power spectra were obtained by squaring the complex Fourier coefficients.

The upper limits to the pulsed flux were derived using the fact

that the fluctuations in the power level of a given frequency bin are distributed exponentially. Thus, the 90% confidence criterion implies that the power in any bin must exceed the local mean power times $\ell n(N/0.1)$, where N is the number of points in the power spectrum. The local mean power was derived by summing the power spectrum over 128 bins and fitting the resulting spectrum to a polynomial, using the least squares fitting technique. The mean power at any frequency was assigned from this smoothed fit. Since this method is less sensitive to fluctuations in the local mean power, it provides a statistically more reliable calculation of the ratio of the power at any frequency to the local mean power than using a short section of nearby power points as a reference. To test the validity of this approach, a sinusoidal "tracer" signal was added to the data and transformed. The tracer amplitude computed from the power spectrum was in close agreement with the amplitude of the original signal.

III. RESULTS

The 90% confidence upper limits to pulsations from GCX are summarized for both detectors in Fig. 2. For periods less than a few minutes the power spectra were well-behaved, i.e., the distribution of power points was exponential. The upper limits increase rapidly for longer periods. Because of spacecraft pointing jitter, the data is insensitive to periods longer than $\sim$ 40 minutes. In Fig. 1, we show only the low frequency portion of a 2^{16} point power spectrum to illustrate how noisy the low frequency data is because of the presence of many harmonics of the orbital

and noninertial periods of the spacecraft. Particularly obvious in Fig. 1 are a large number of very high harmonics of the orbital period. To check that these were due to periodicities in the "window function", i.e., the pattern of data and gaps in the sequence of orbits used as input to the transform, and not to real periodicities in the data, we Fourier transformed the window function itself. This was accomplished by assigning a value of 1 to all the real data values, and a value of 0 to all the gaps. The same pattern of high harmonics resulted from this transform as from the transform of the real data. The periodicities in the window function are due to earth occultations, South Atlantic Anomaly crossings, and transmission gaps. The fact that the power is so high in these harmonics simply means that the data covering many hours of observation cannot be fit to the simple mean value we used to pad the gaps. The fluctuations in the background are definitely in excess of Poisson statistics, but this is not confined to the GCX region. SAS-3 observations of other areas of the sky show similar noisy background behavior (Doty, private communication). We should point out that the high frequency ($P <$ a few minutes) portion of the power spectrum was not affected by the background noise, as was proved when we again transformed the original data, this time fitting each uninterrupted data stream ($\leqslant$ 30 minutes long) to a low-order polynomial. The high frequency upper limits were the same using both reduction techniques. Of course, with the latter technique, we were insensitive to periods greater than a few minutes.

The major contributor to the GCX background is the cosmic ray background. We attempted to measure this background using earth

occultation data. The X-ray sky background (non-cosmic) is not known, but is probably less than 0.01 ct cm^{-2} s^{-1} per detector. Subtracting the cosmic ray background only, we calculate that the flux from GCX changed between the two February observations ($\sim$ 1 year apart) from 0.10 to 0.14 cts cm^{-2} s^{-1} in the argon detector, and from 0.04 to 0.07 cts cm^{-2} s^{-1} in the xenon detector. We note that the increase in flux from GCX in 1977 February over the 1976 February measurement might have been due to the presence of a variable source or a transient source which had steady emission, as well as burst activity. The SAS-3 Observatory detected a two-fold increase in the number of bursts in 1977 February, as compared to the observation one year before (Lewin, Hoffman, and Doty 1977).

The best upper limits range from $\sim 1.6 \times 10^{-3}$ cts cm^{-2} s^{-1} for periods $\leqslant$ 20 s to $\sim 1.0 \times 10^{-2}$ cts cm^{-2} s^{-1} for periods of order 20-30 minutes in the energy range 2.5 - 10 keV. These correspond to pulsed fractions of the total GCX flux of 1.1% and 7.0%, respectively. At higher energies (i.e., in the 8 - 35 keV band) these limits range from $\sim 2.3 \times 10^{-3}$ cts cm^{-2} s^{-1}, or 3.3% of the total GCX flux for periods $\leqslant$ 6000 s, to 6.7×10^{-3} cts cm^{-2} s^{-1}, or 9.5% of the total GCX for longer periods. Only the pulsed amplitude of the orbital period of the spacecraft and the first few harmonics of this period exceeded these upper limits.

It is fruitful, as a guide for future observations, to ask what is the upper limit to the pulsed fraction from a discrete, steady-state, source in GCX based on the results quoted here. As an example, the flux from GCX-3, one of the 4 discrete sources in GCX discovered by Cruddace

et al. (1977), comprised ~ 17% of the total GCX flux measured in their observation. Hence, our upper limit implies that the pulsed fraction of this source in the regime 2.5 - 10 keV must be no greater than 8% for periods from ~ 2 - 60 s. Most of the pulsating galactic sources (Pop. I) have pulsed fractions between 20 and 100%.

IV. SUMMARY

Since the search for pulsations from the direction of galactic center was begun, numerous SAS-3 pointings of GCX have been carried out, and the data from these observations will be similarly searched for periodic phenomena. However, from this initial study, which draws on data taken during long observations separated by one year, it is observed that there are no steady short period pulsations to a limit of ~ 1.3% of the total GCX flux in the range 2.5 - 10 keV, and 3.3% in the range 8 - 35 keV. For longer periods, this upper limit becomes several times higher.

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REFERENCES

Ariel V Group, University of Birmingham. 1976, I.A.U. Circular No. 2934.

Cruddace, R. G., Fritz, G., Shulman, S., and Friedman, H. 1977,

Eyles, C. J., Skinner, G. K., Willmore, A. P., and Rosenberg, F. D. 1975, Nature, 257, 291.

Ives, J. C., Sanford, P. W., and Bell-Burnell, S. J. 1975, Nature, 254, 578.

Kellogg, E., Gursky, H., Murray, S., Tannanbaum, H., and Giacconi, R. 1971, Ap. J. (Letters), 169, L99.

Lewin, W. H. G., Hoffman, J. A., Doty, J., Hearn, D. R., Clark, G. W., Jernigan, J. G., Li, F. K., McClintock, J. E., and Richardson, J. 1976a, M.N.R.A.S., 177, 83.

Lewin, W. H. G., Li, F. K., Hoffman, J. A., Doty, J., Buff, J., Clark, G. W., and Rappaport, S. 1976b, M.N.R.A.S., 177, 93.

Lewin, W. H. G., Hoffman, J. A., and Doty, J. 1977, I.A.U. Circular No. 2934.

Rosenberg, F. D., Eyles, C. J., Skinner, G. K., and Willmore, A. P. 1975, Nature, 256, 628.

FIGURE CAPTIONS

Fig. 1. The low frequency portion of the 1977 Feb GCX power spectrum (2.5 - 10 keV) showing the difficulty of extracting periods > 40 minutes owing to spacecraft pointing jitter. Several of the harmonics of the orbital period P_o of 94.3 minutes and noninertial period P_n of 101 minutes are specifically denoted, while the numerous harmonics at higher frequencies are simply indicated with markers. Because of the nature of the discrete fast fourier transform algorithm, the entire power spectrum has only 16 points, or one-half the number of input data. Each datum represents a $\tau = 0.8314$ s integration. Thus the frequency f = harmonic No./($2^{17} \times \tau$) Hz.

Fig. 2. The dependence of the upper limit to the pulsation amplitude on the period being searched for the 1976 Feb and 1977 Feb observations (Fig. 2a and 2b, respectively). Tabulated in the upper right-hand corner are the dates and duration of each observation and the total GCX flux in cts s^{-1} per energy interval.

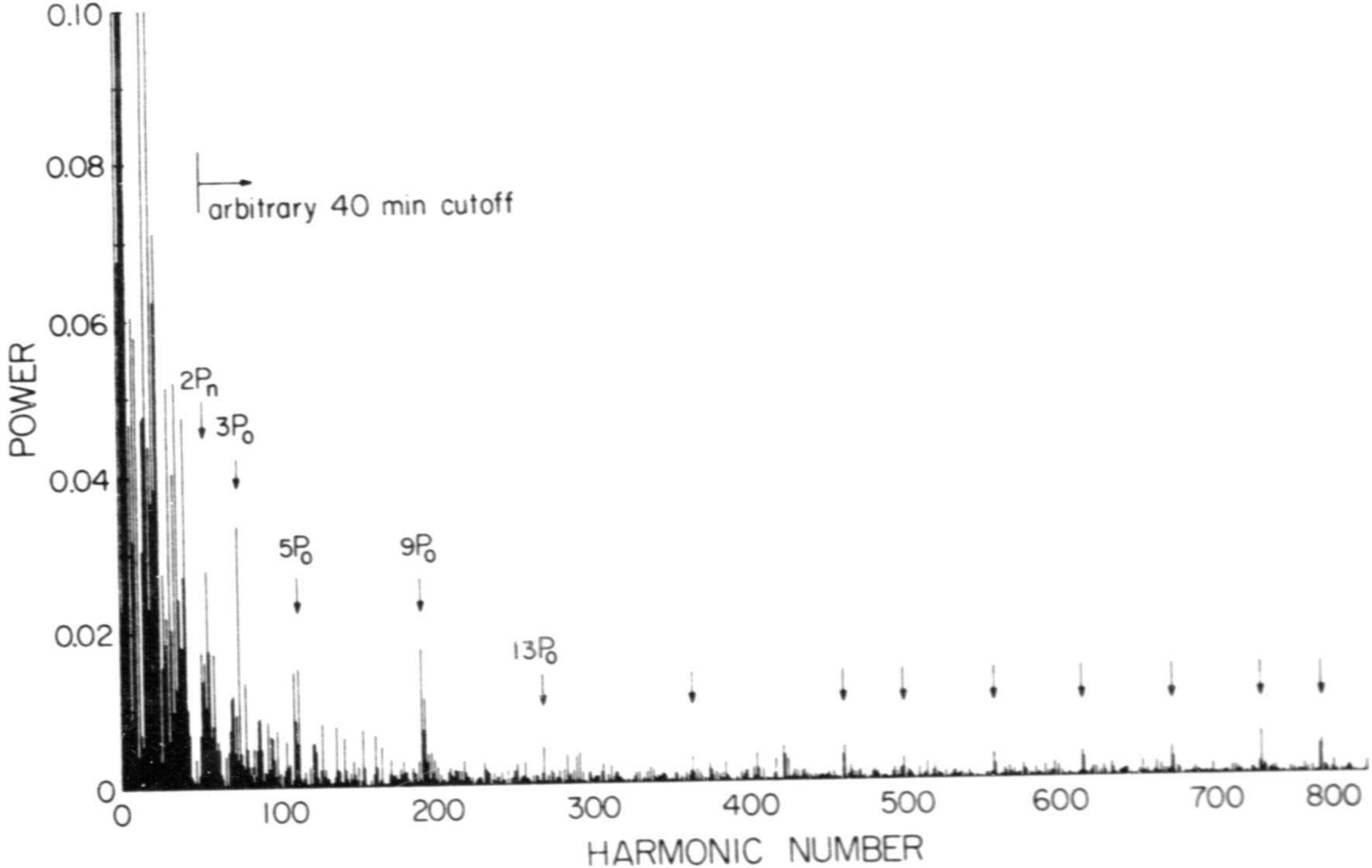
0.10
0.08
0.06
0.04
0.02
0
POWER
arbitrary 40 min cutoff
2Pn
3Po
5Po
9Po
13Po
0
100
200
300
400
500
600
700
800
HARMONIC NUMBER

Figure 1

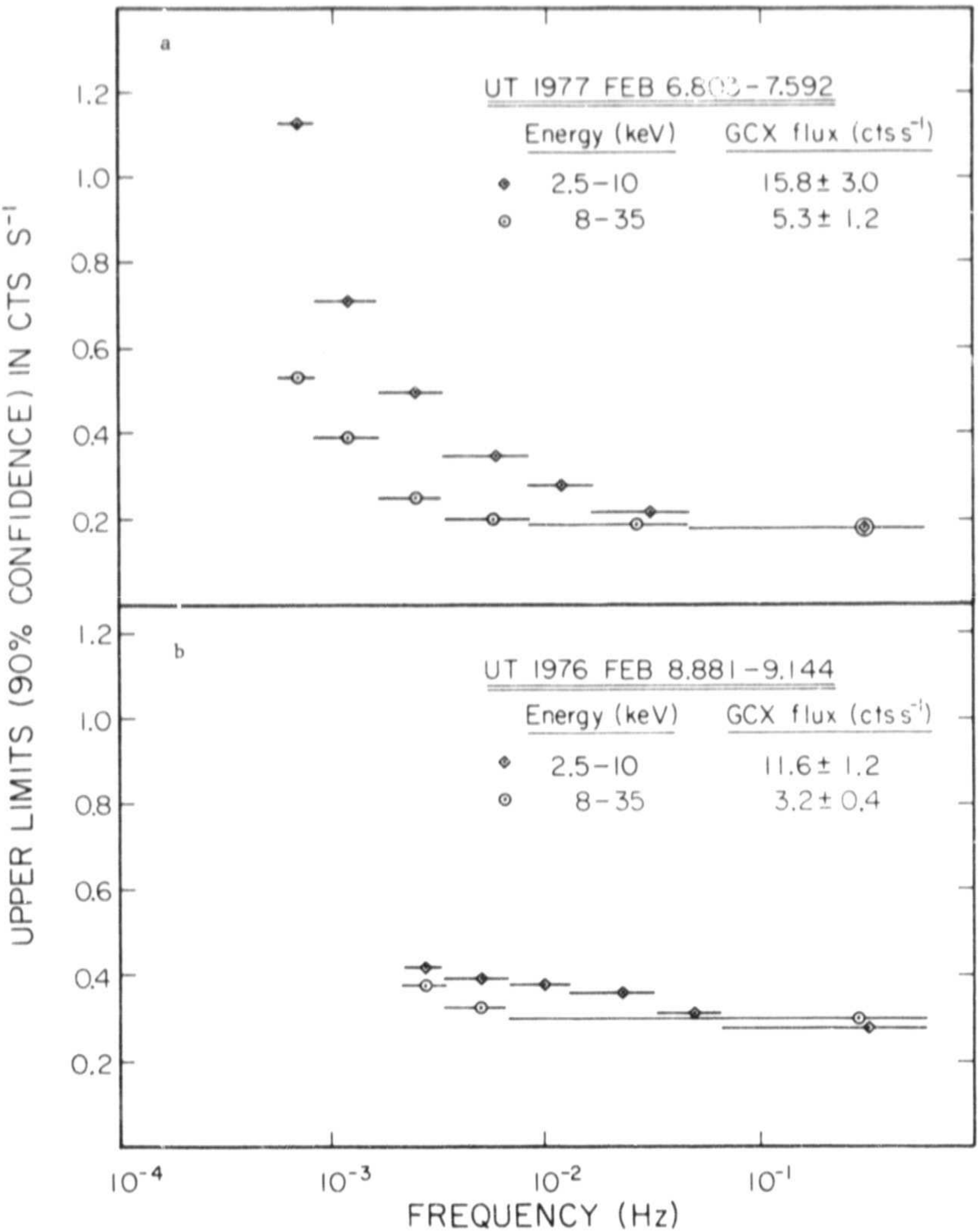
a
UT 1977 FEB 6.8
-7.592
Energy (keV)
GCX flux (cts s^{-1})
2.5-10
15.8 ± 3.0
8-35
5.3 ± 1.2
b
UT 1976 FEB 8.881-9.144
Energy (keV)
GCX flux (cts s^{-1})
2.5-10
11.6 ± 1.2
8-35
3.2 ± 0.4
UPPER LIMITS (90% CONFIDENCE) IN CTS S^{-1}
1.2
1.0
0.8
0.6
0.4
0.2
10^{-4}
10^{-3}
10^{-2}
10^{-1}
FREQUENCY (Hz)

Figure 2